Antenna axis offsets estimated in VLBI data analysis

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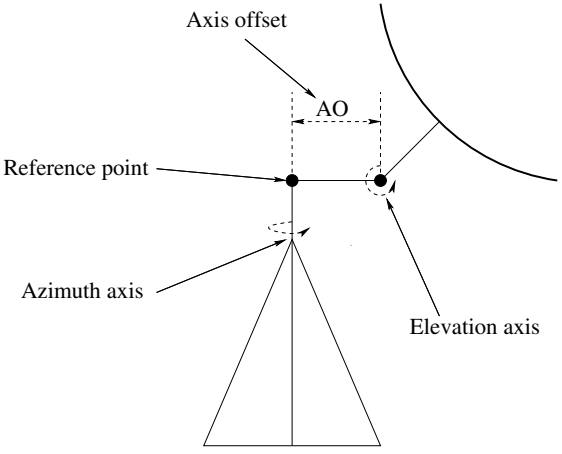
Introduction

- The reference point of a VLBI antenna is theoretically defined as the intersection of the two axes of rotation.
- However, in practice the axes do not intersect exactly:
  - Some antennas are designed with an offset between the axes. Could be several meters.
  - It is difficult to align the axes precisely (sub-mm) when constructing the antenna
- The axis offsets need to be considered in the VLBI data analysis
- Determining the axis offsets:
  - Measure the axis positions in a local survey. Currently available only for a few IVS sites.
  - Estimate the offset in the VLBI data analysis.
- Aim of this work:
  - How accurate can the axis offsets be determined in the VLBI data analysis?
  - What are the potential error sources?

Axis offsets of VLBI telescopes

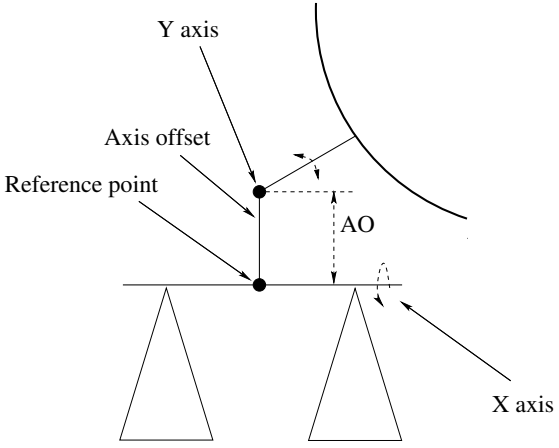
Azimuth-Elevation mount:



Delay correction due to axis offset:

$$\delta l_{ao} = -AO \cdot \cos el$$

X-Y mount:



Delay correction due to axis offset:

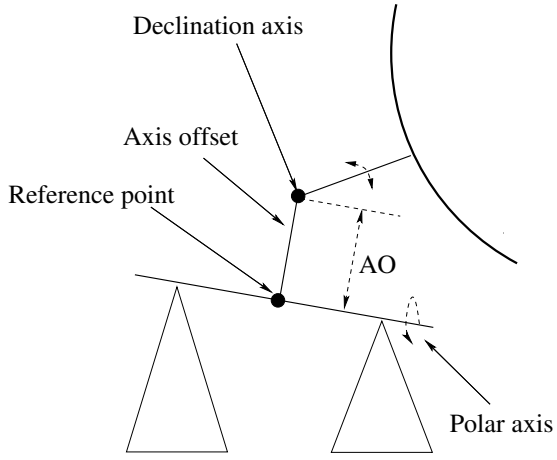
$$\delta l_{ao} = -AO \cdot \sqrt{1 - (\cos\epsilon \cos\alpha)^2}$$

for X-axis in N-S direction, and

$$\delta l_{ao} = -AO \cdot \sqrt{1 - (\cos\epsilon \sin\alpha)^2}$$

for X-axis in E-W direction

Equatorial mount:



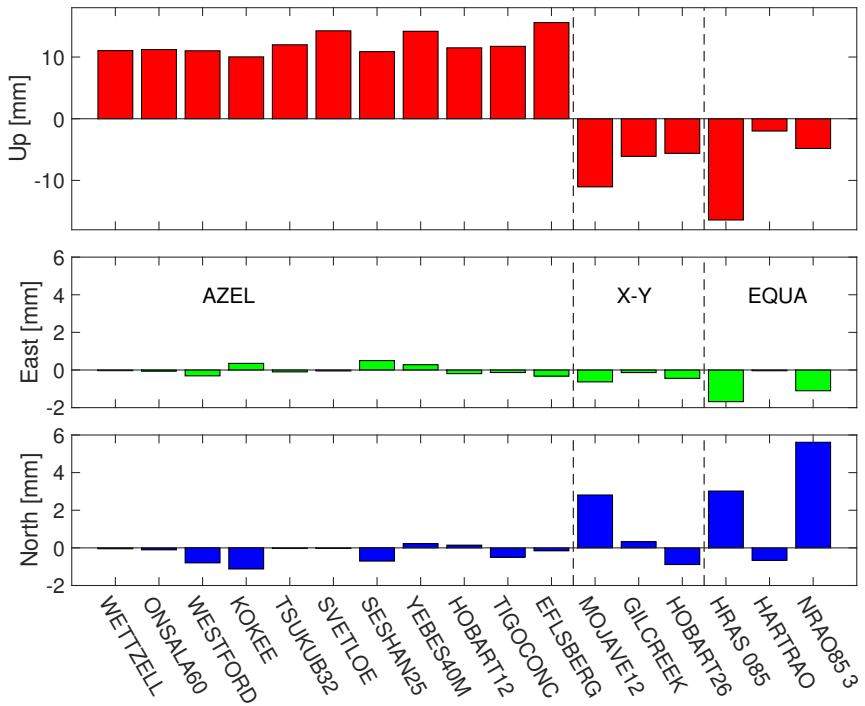
Delay correction due to axis offset:

$$\delta l_{ao} = -AO \cdot \cos\delta$$

Data analysis

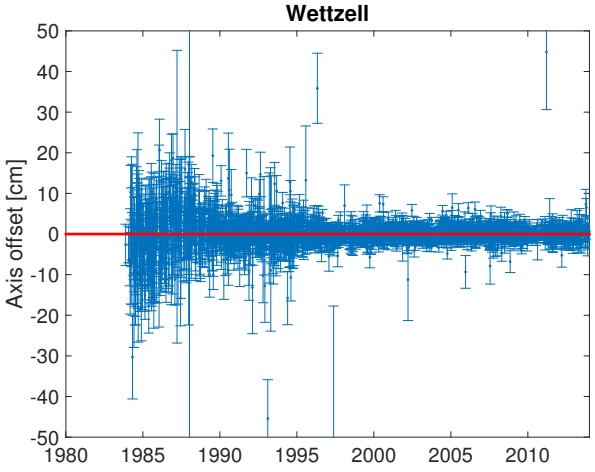
- We analyzed 4241 VLBI sessions, based on the GFZ contribution to ITRF2014 (*Heinkelmann et al., 2014*), covering the period 1980-2013
  - At least four stations with >100 observations
  - Volume of station network polyhedron $>10^{15}$ m^3
- The data were analyzed with the GFZ version of the Vienna VLBI Software, VieVS@GFZ
- Global solution, estimating:
  - Axis offsets (one offset per station)
  - Terrestrial reference frame (positions and velocities + breaks when needed)
  - Celestial reference frame
- The solution contains:
  - 143 stations
  - 3384 sources (39 special handling sources were reduced session-wise)

Effects of axis offset errors on station coordinates

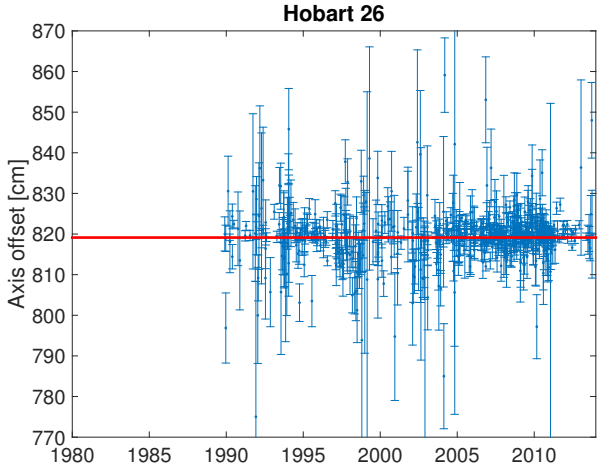


- Station position error resulting from a shift the axis offset of a station by $+1$ cm
- Results from global VLBI solution using data from 1980-2013
- To reach millimeter accuracy for station coordinates, we need to know the axis offset with sub-mm accuracy.

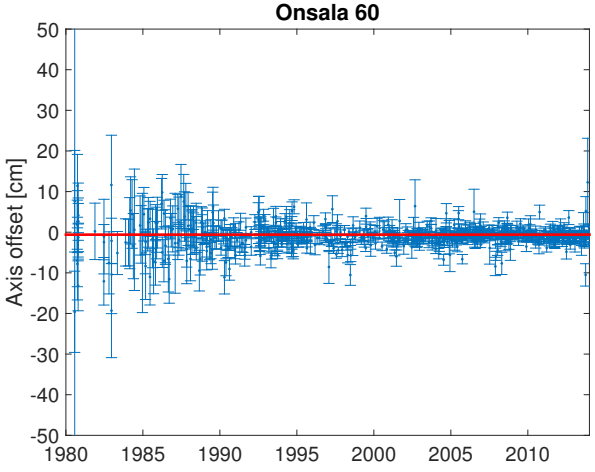
Estimated axis offset time series



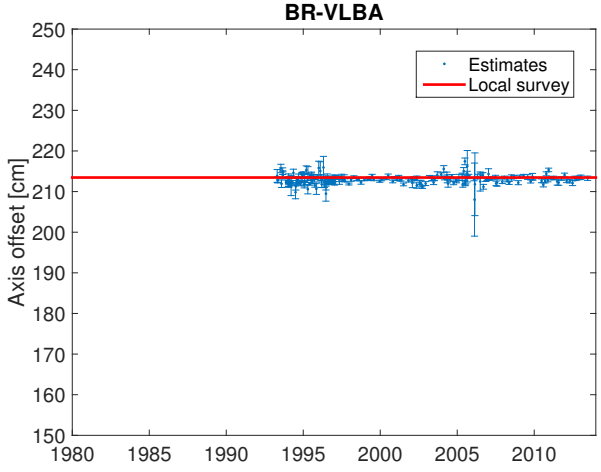
WRMS: 1.25 cm



WRMS: 2.41 cm

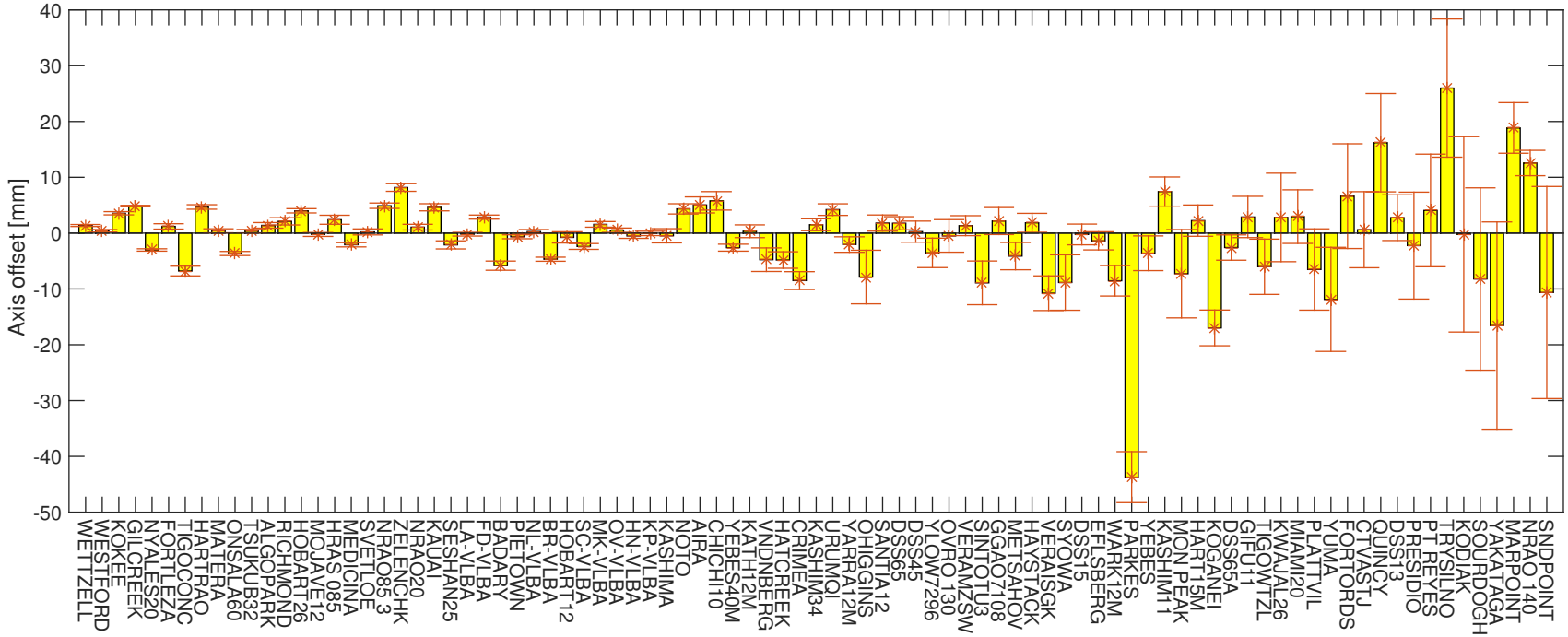


WRMS: 1.36 cm



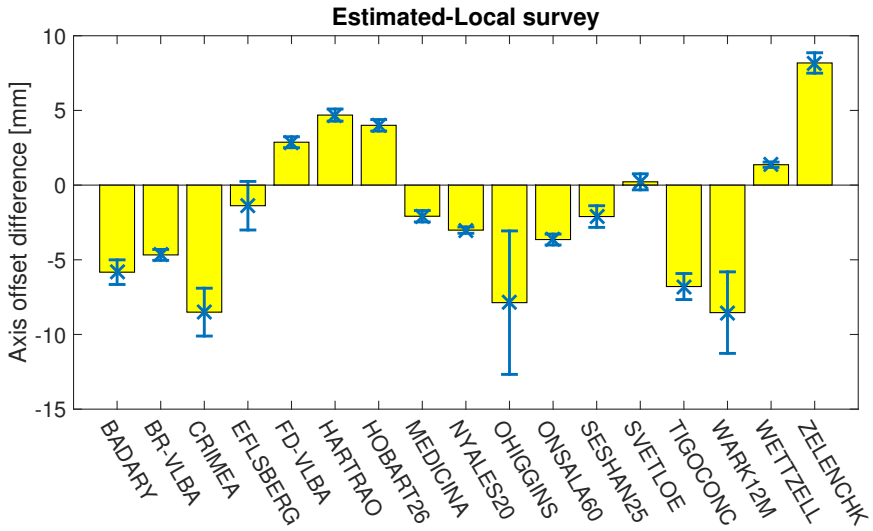
WRMS: 0.74 cm

Estimated axis offsets



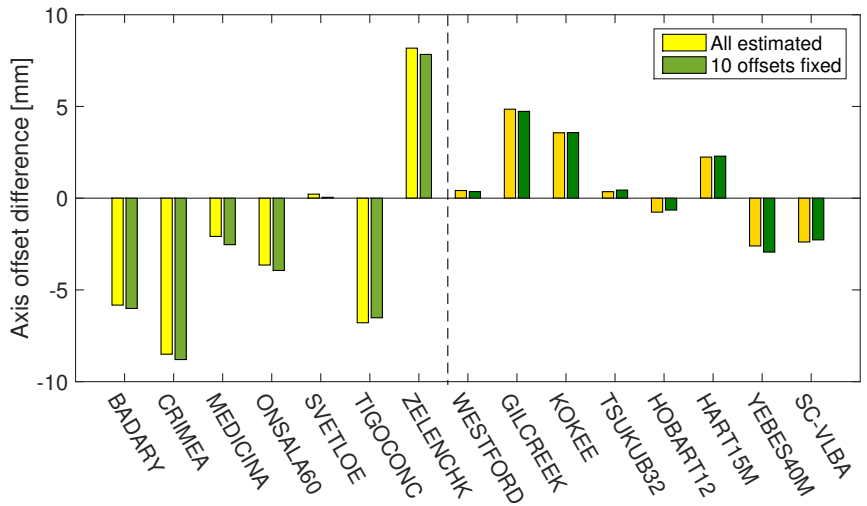
- Estimated axis offsets for all stations observed in at least ten of the sessions
- Stations sorted by number of sessions
- Shown are the difference to the a priori values (the values given in the file `http://vlbi.geod.uni-bonn.de/Analysis/Thermal/antenna-info.txt`, courtesy A. Nothnagel)
- Error bars are formal errors from the VLBI analysis

Estimated axis offsets (II)



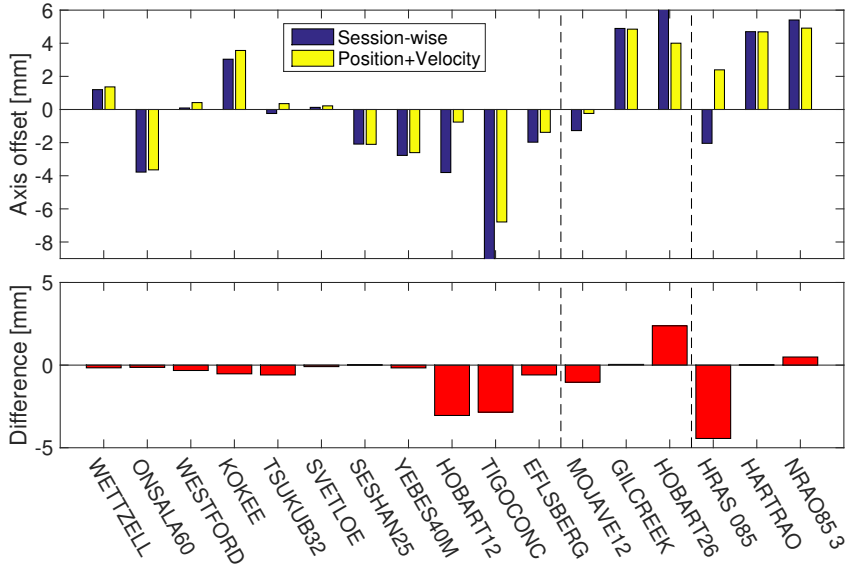
- Differences between estimated axis offsets and results from local surveys
- Error bars indicate the formal errors of the axis offset estimated in the VLBI analysis
- The differences are a few millimeters. Why?

Effect of fixing some offsets



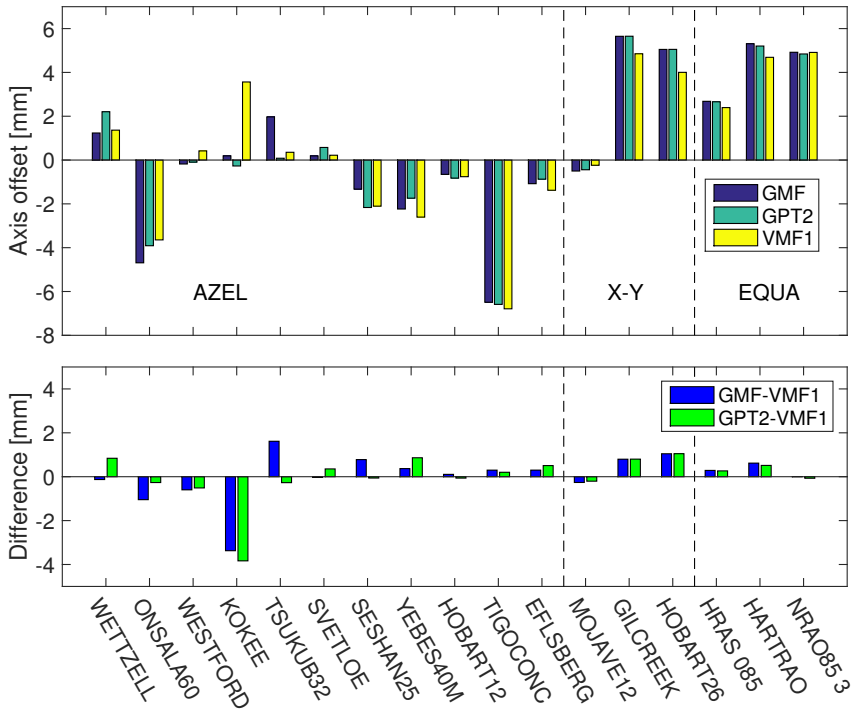
- The axis offsets of 10 stations (BR-VLBA, Effelsberg, FD-VLBA, HartRAO, Hobart 26, Ny-Ålesund, O'Higgins, Seshan 25, Warkworth, and Wettzell) were fixed to their a priori values (from local surveys)
- No significant effects on the estimated axis offsets of other stations

Modeling of station and radio source coordinates



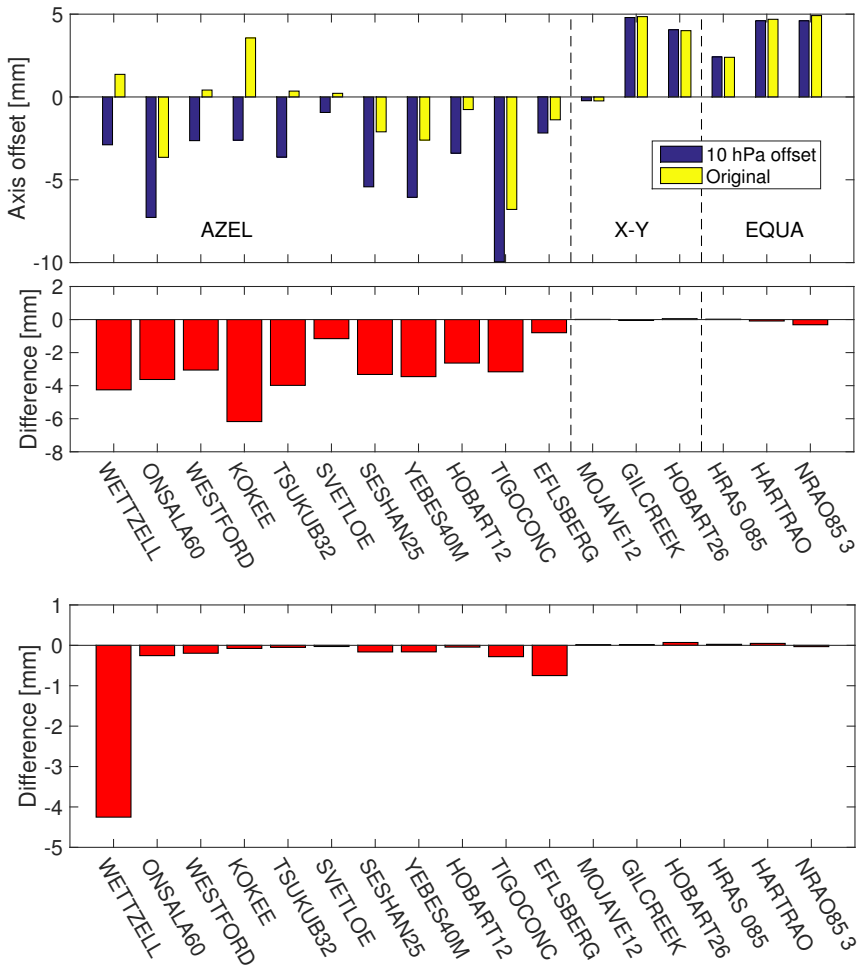
- We made a solution where all station and radio source coordinates were reduced session-wise (only axis offsets estimated globally)
- Changes the axis offsets for some stations by a few millimeters
- Possible reason: non-linear motion not precisely modeled in our TRF solution (e.g. for TIGO)

Effect of mapping function



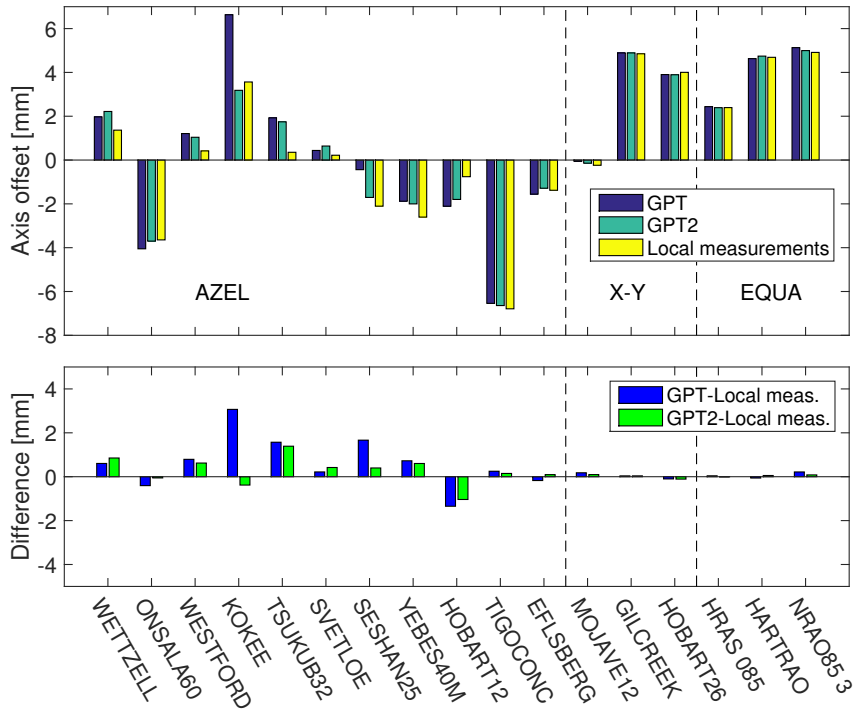
- Differences in estimated axis offsets when using the GMF or the GPT2 mapping function instead of VMF1
- Typically small effect, but 4 mm at Kokee

Effect of pressure offsets



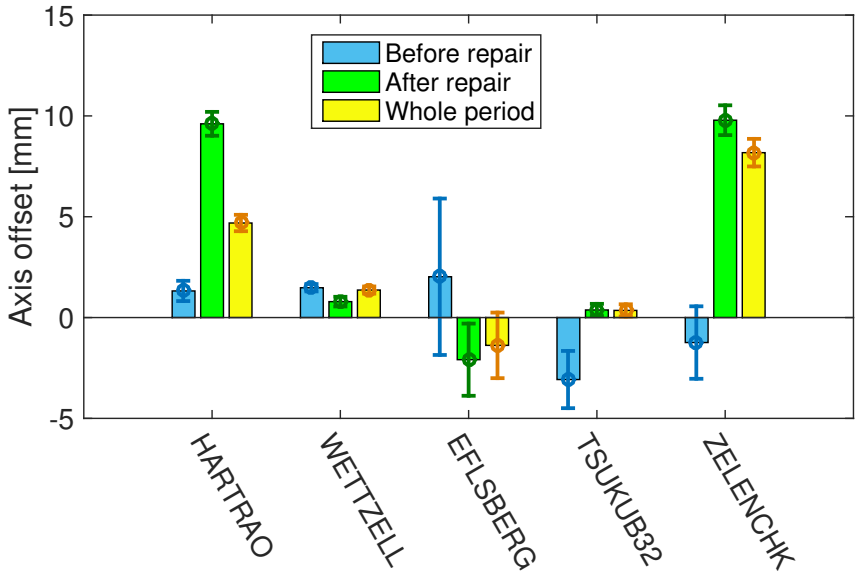
- Effect on the estimated axis offsets of a 10 hPa offset in the pressure measurements at the stations
- Generally around 3 mm for AZEL mount antennas, for other mounts the effect is negligible
- Lower plot: Effect of a 10 hPa pressure offset at Wettzell on other stations

Effect of pressure offsets (II)



- Estimated axis offsets when using pressure from GPT or GPT2, compared to when using local measurements
- Effect is about 1 mm at some stations with AZEL mounts

Effects of antenna repairs



- The a priori values for HartRAO, Wettzell, Effelsberg, and Zelenchukskaya are all from local surveys, all measured before the repair.

- Major antenna repairs could potentially change the axis offsets
- We made a solution where the following breaks in axis offsets were considered (corresponding to antenna repairs):
  - HartRAO: Jan. 2009
  - Wettzell: Oct. 2010
  - Effelsberg: Oct. 1996
  - Tsukuba 32: May 1999
  - Zelenchukskaya: Jul. 2007

Conclusions

- The axis offsets estimated in the VLBI global solution differ from the values from local surveys by several millimeters
- Possible reasons:
  - Unmodeled non-linear station motion
  - Mapping function errors
  - Pressure offsets
    - Important that pressure sensors are well calibrated
    - Pressure need to be corrected to the level of the reference point
- Future work:
  - Test different elevation cut-off angles (could reduce the impact of mapping function and pressure errors)

Thank you for your attention!

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